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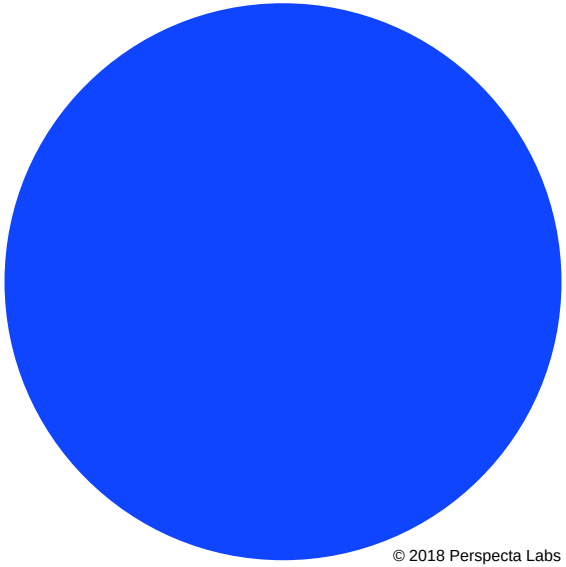
Cellular Telemetry Enhancements in 5G

Achilles Kogiantis, Ph.D.
Kiran Rege, Ph.D.
Anthony Triolo, Ph.D.



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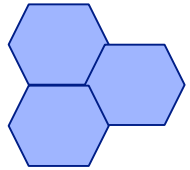
Overview

Key Areas of Improvement with 5G

- Problem Statement and Current Milestones with 4G Cellular in the Testing Range
- 5G Status: Standards and Vendor Ecosystem Directions
- Key 5G Enhancements with direct impact to TRMC
  - mmWave Bands and Beamforming
  - Non-Terrestrial Networks
  - Mobility Enhancements
  - In-Band Backhauling
  - Graceful Migration Path from 4G to 5G

4G LTE Feasibility in the Testing Range

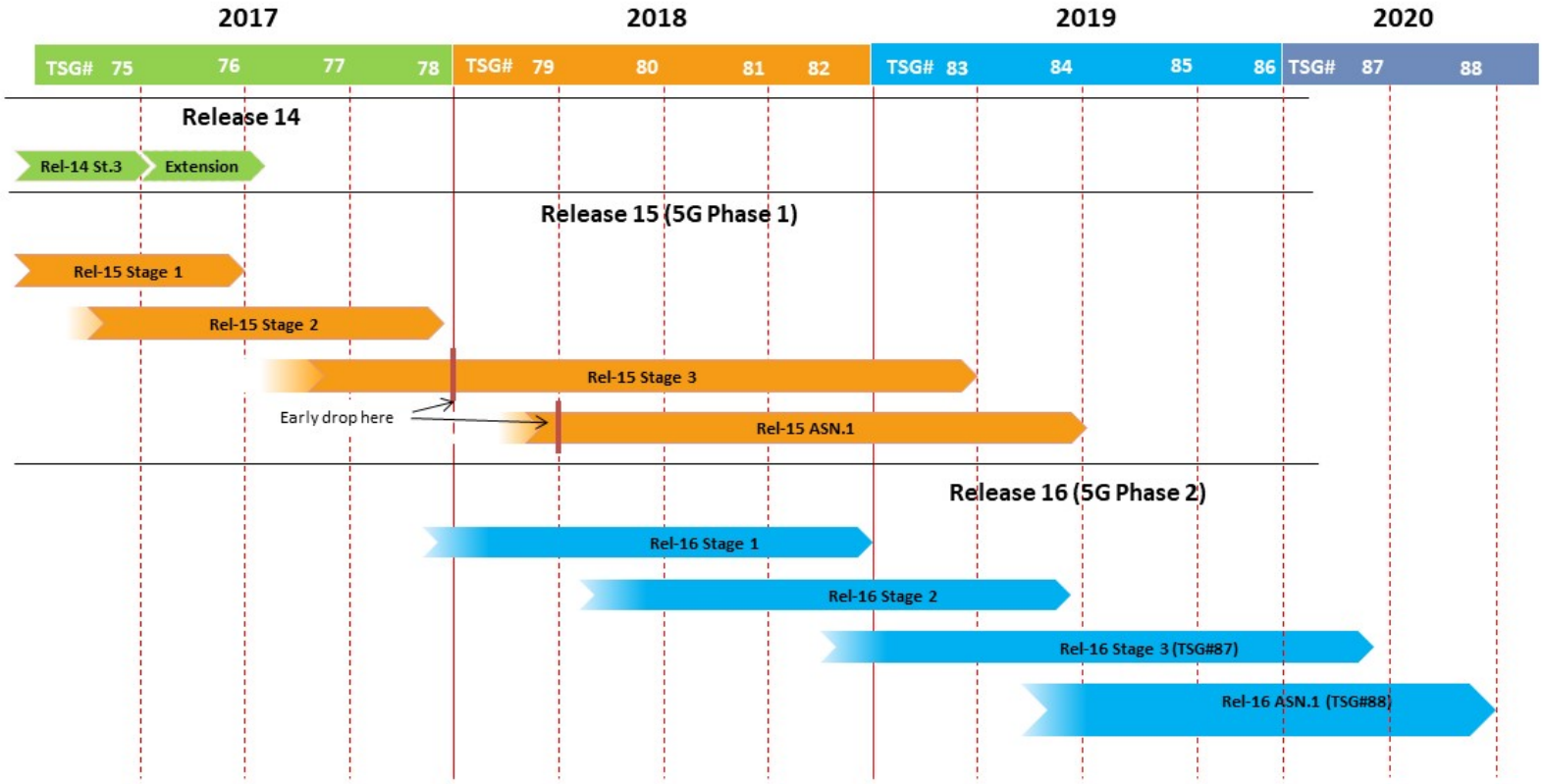


- Cellular approach to serving telemetry links in the test range -> Spectral efficiency and automated multi-test frequency coordination via frequency reuse and LTE’s multi-user scheduling
- 4G augmentation of 4G LTE transceiver for aeronautical speeds proven functional with no disruption to 4G signaling or physical layer
- Delivery of high data rates with full duplex links
- Availability of COTS equipment and vendor selection
- Ongoing over-the-air testing in the test range

5G Standards – Current Status & Timeline

Evolution of LTE technology

- Developed within the 3GPP specifications body – as a new Series starting with Rel-15
- Rel-15 introduced with brand new Radio Access and Core Network definitions
  - Advanced Physical Layer compared to LTE (NR)
  - Enhanced Signaling Mechanisms compared to LTE
  - New Core Network architecture – more streamlined than LTE
- Timeline: First Release, Rel-15 ready since early 2019



NR mmWave above 6GHz approved bands

- Current Specifications include:

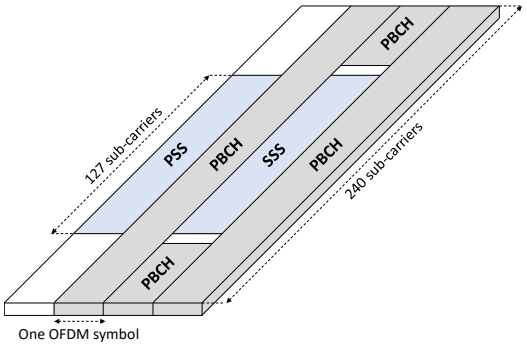
Operating Band	Uplink (UL) operating band BS receive UE transmit	Downlink (DL) operating band BS transmit UE receive	Duplex Mode
	F_{UL_low} – F_{UL_high}	F_{DL_low} – F_{DL_high}	
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	27500 MHz – 28350 MHz	TDD

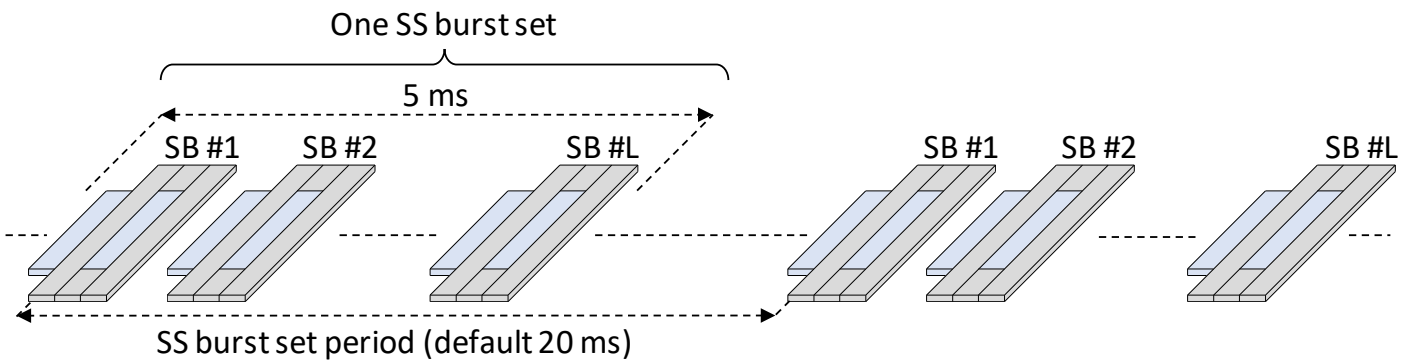
- In the US, new spectrum to be allocated at 37, 39, and 47GHz

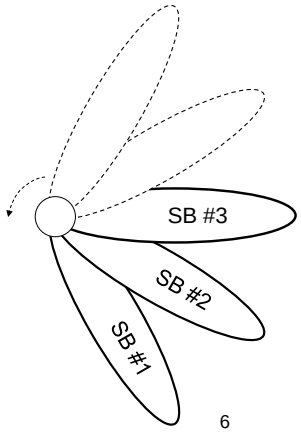
5G NR mmWave & Beamforming

- To close the link in NR mmWave, beamforming is required at both the base station and the mobile device.
- Macro-cell coverage with mobility is already commercially trialed at 24GHz, in the US
- *5G* Signaling mechanisms enhanced to operate with beamforming
  - Cell search and initial random access include beam search with up to L=64 beams
  - Beam tracking is continuous

PSS: Primary Synchronization Sequence
SSS: Secondary Synchronization Sequence
PBCH: Physical Broadcast Channel
SS Block: System Synchronization Block







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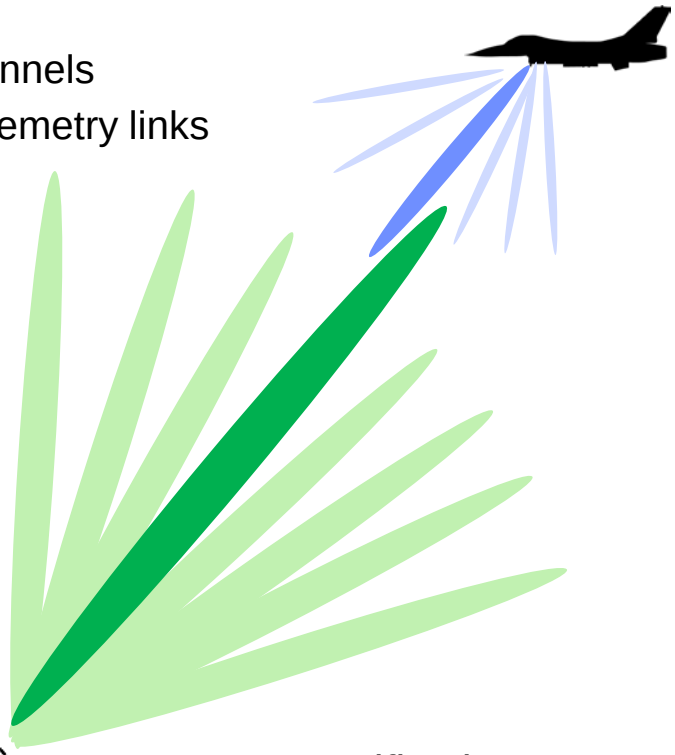
5G NR – mmWave and BF

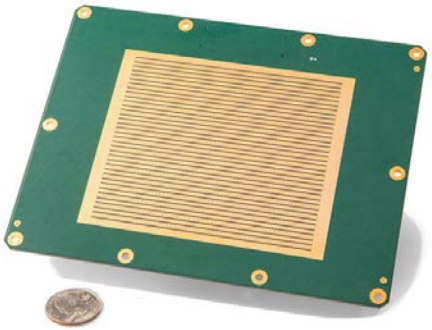
High Frequency Operation in NR

- Beam switching over a set of 64 beams at mmWave in a commercial 1-2Km cell is now in field. A larger cell in the test range is within reason
  - Extend range with much larger antenna arrays
  - Simultaneous beams pointing to multiple test articles
- mmWave offers capability for 100MHz – 400MHz wide channels
  - can support the needs for concurrent 100Mbps F-35 Telemetry links
- BF at both ends provides interference protection:
  - Against other co-channel links (spectrum re-use)
  - Coexistence with legacy Telemetry

Qualcomm 27-40GHz Transceiver and phased array



ANSYS 28GHz Phased 8x8 Antenna Array



NR Specifications:

- 100-400MHz channels
- Up to 64 beams codebook

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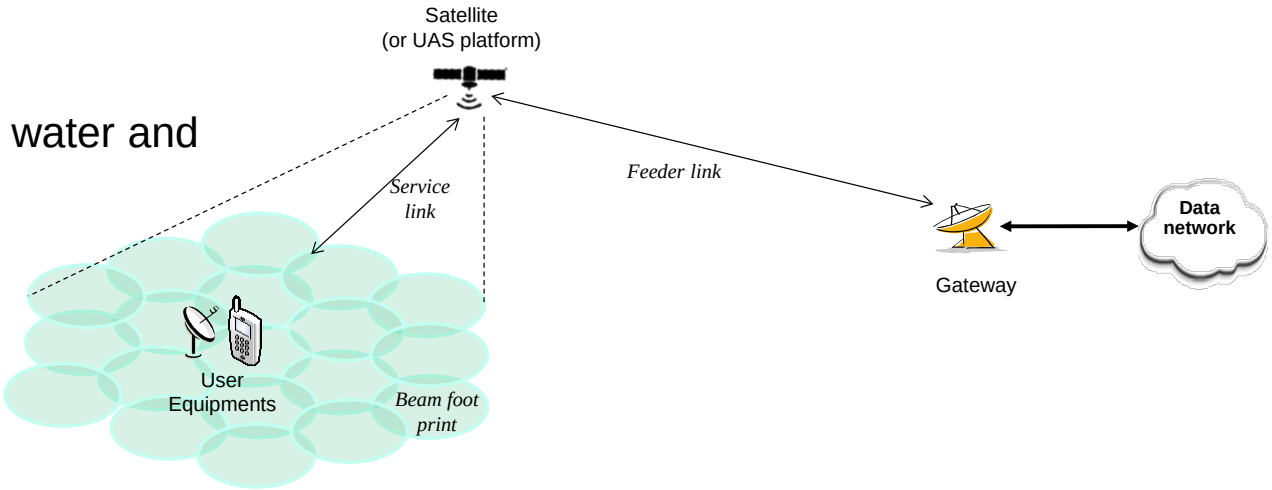
5G Non-Terrestrial Networks (NTN)

Satellite and High-Altitude Links

- Strong industry interest has driven the study (and upcoming standardization for Rel-17) of NR to accommodate links between terrestrial (train and airplane inclusive) and LEO/MEO/GEO satellites or High Altitude aircraft.
- Development of pre-specification enhancements needed currently being drafted, TR 38.821:
  - Timing and Frequency Acquisition (augmented by ephemeris)
  - Timing Advance extension
  - Random access and response window
  - Physical layer link quality control loops and HARQ modifications
  - Window size changes for Layer 2/3 protocols, user plane timer extensions
  - Handover robustness to latency

At the Testing Range

- Serve remote areas over water and inter-range transitions

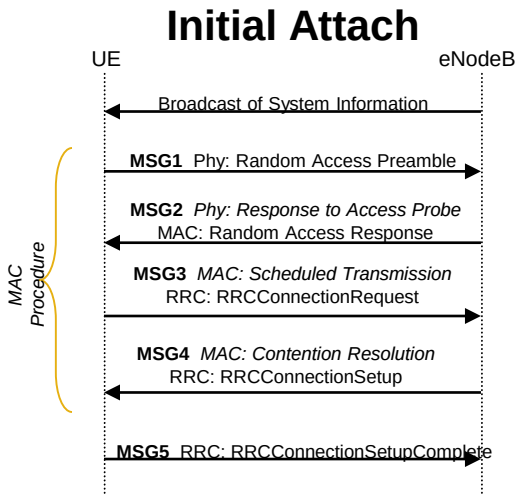


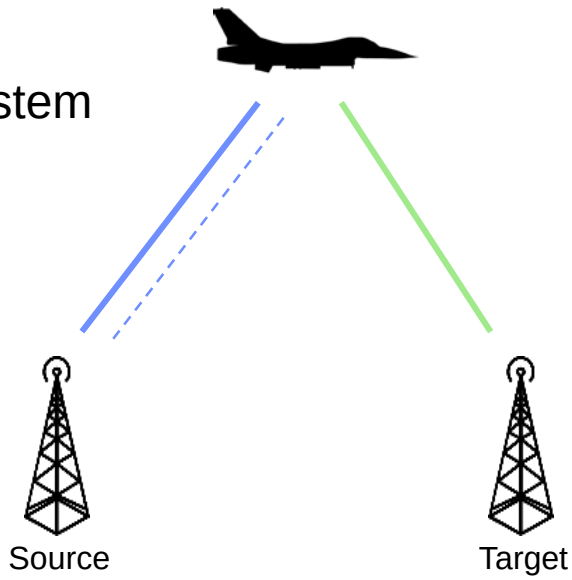
Field of view of the satellite (or UAS platform)

5G NR – Mobility Enhancements

Increase robustness & speed (reduce interruption time)

- Feature is currently in development
- Reduce Interruption Time (0msec interruption): Adoption of Make-Before-Break (MBB) mechanism
  - RACH-less handover
    - Prepares all parameters of target cell in advance
  - Simultaneously connect to source & target using Dual Connectivity principles
- Increase Robustness
  - Conditional Handover: Prepare multiple cells as candidates to be the target
  - Fast handover failure recovery: Do not wait for system information broadcast measurements (SIB/MIB)





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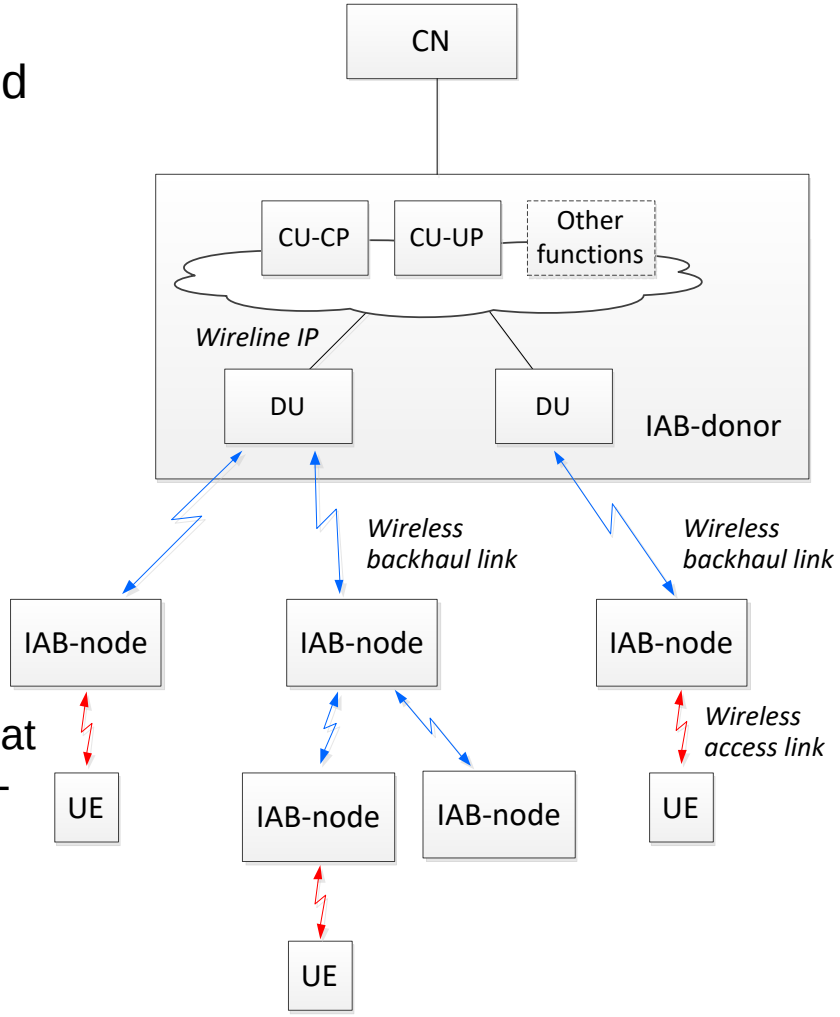
In-Band Backhauling in 5G

Integrated Access and Backhaul (IAB) feature in NR

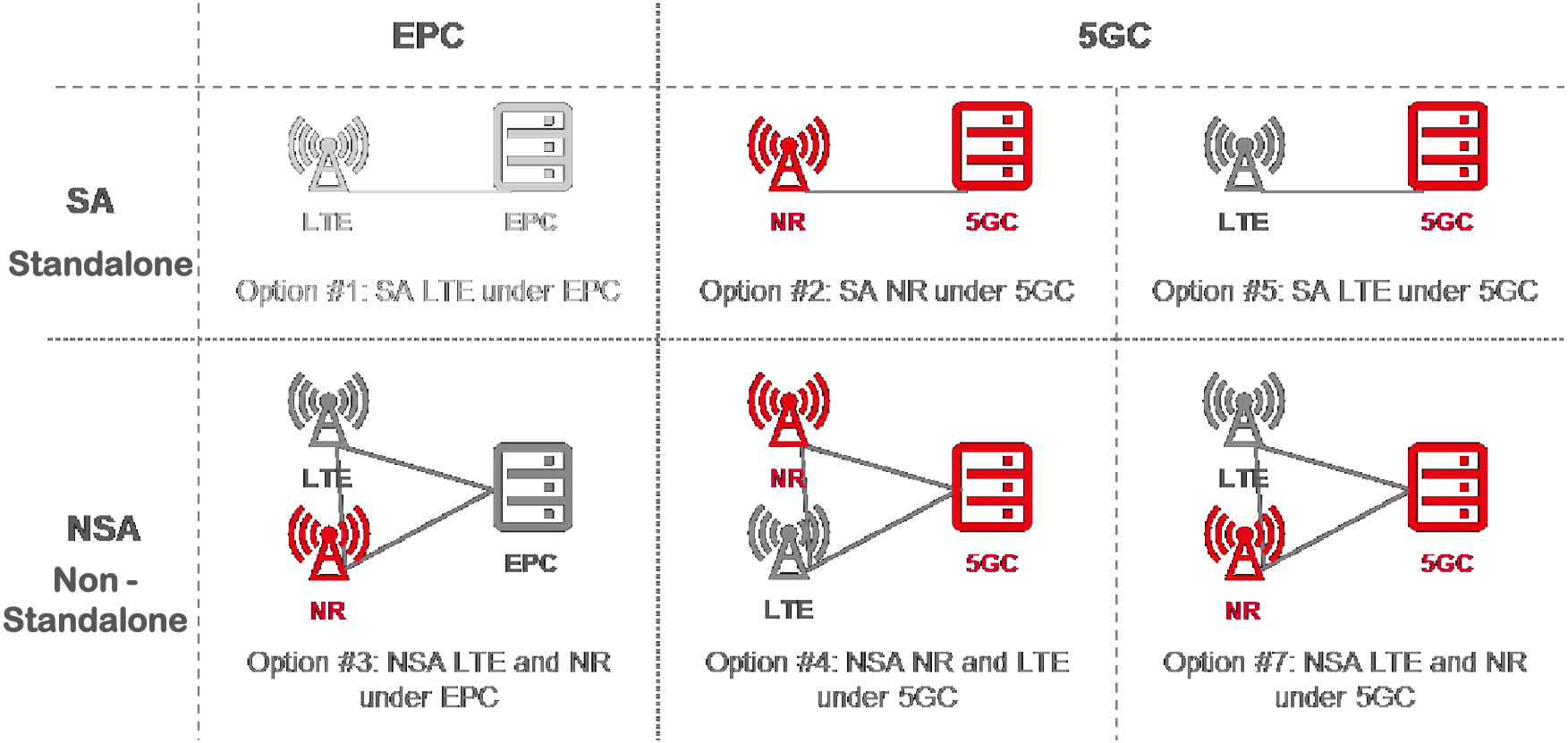
- IAB enables flexible extention to an existing 5G network without need to deploy new wired transport network
  - Topology management for single-hop/multi-hop and redundant connectivity
  - Route selection and optimization
  - Dynamic resource allocation between the backhaul and access links
  - High spectral efficiency while also supporting reliable transmission
- Use Cases:
  - IAB with physically fixed relays
  - In-band backhauling: access and backhaul link at least partially overlap in frequency creating half-duplexing or interference constraints
  - Out-of-band backhauling
  - Backhauling of NR-access traffic over NR backhaul links



4G Migration to 5G

Gradual transition of a 4G network to 5G

- 3GPP specifications have been developed for gradual introduction of 5G into an existing 4G network (Migration)
- An existing capital investment to deploy a 4G network now is also in use with 5G
- Architecture options and various migration plans are supported starting with Rel-15 LTE



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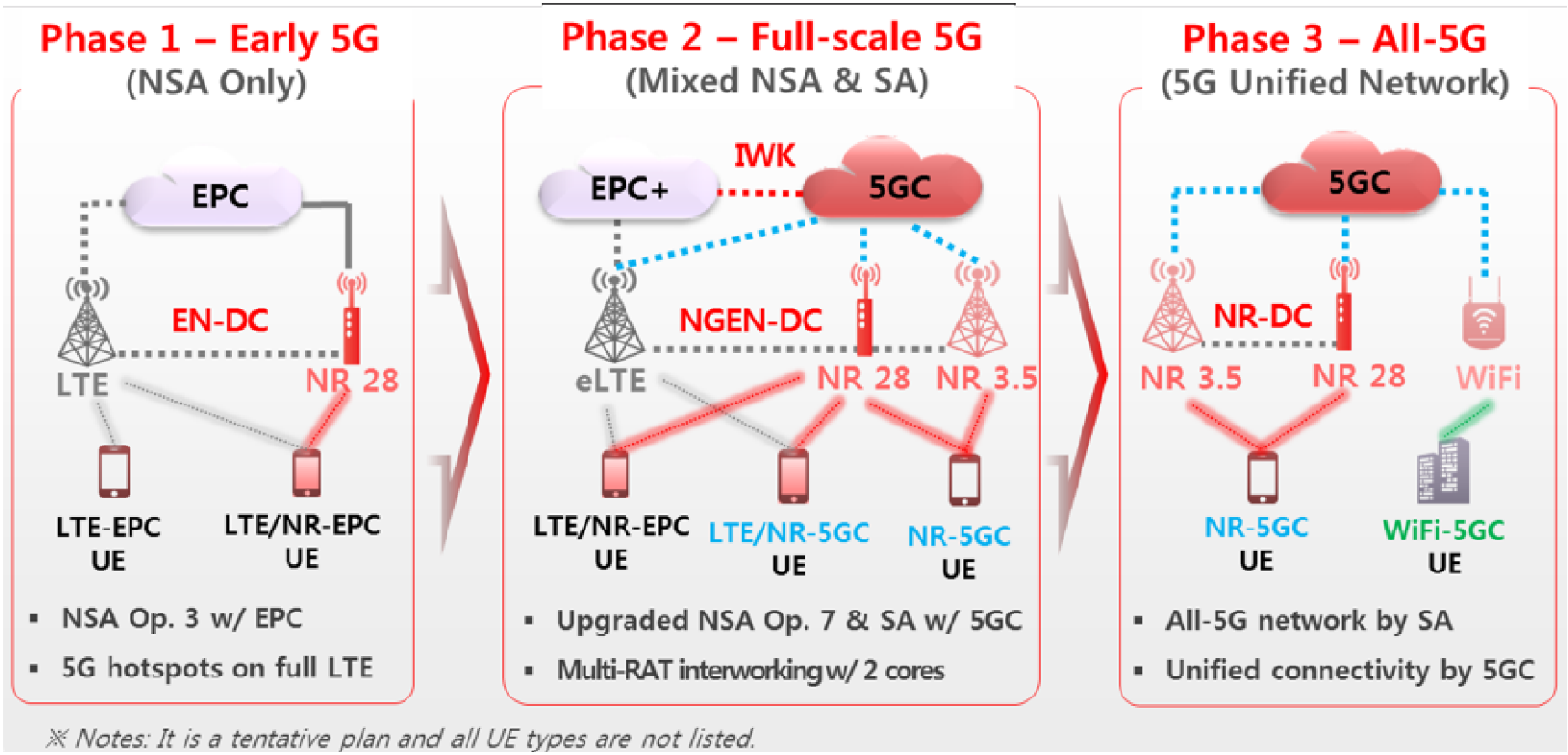
From GSMA: ROAD TO 5G: INTRODUCTION AND MIGRATION, April 2018

4G Migration to 5G - Example

Gradual transition of a 4G network to 5G

- Assumes a Rel-15 User Equipment (UE)
- Initially introduce NR gNBs on 4G EPC (Option 3).
- Then introduce 5GC and transition to Option 7
- Final stage is use of NR and 5GC in Standalone (SA)



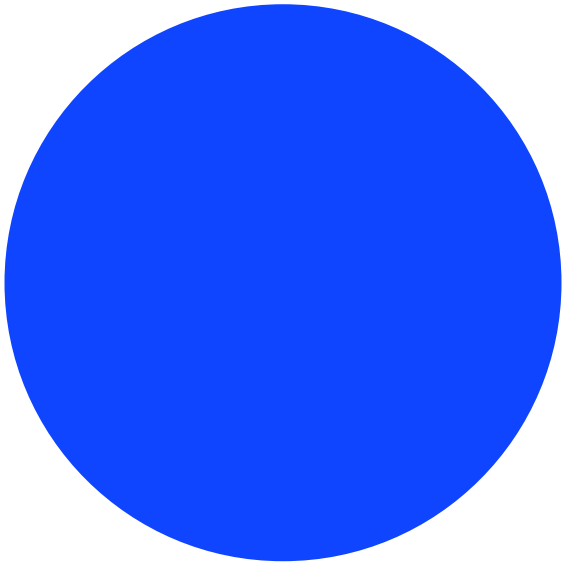
※ *Notes: It is a tentative plan and all UE types are not listed.*

From GSMA: ROAD TO 5G: INTRODUCTION AND MIGRATION, April 2018

Summary

- The first 5G standards release is complete.
- 5G Rel-15 components are available within 2019
- Additional important features to be introduced in Rel-16 and Rel-17
- Migration Path from 4G to 5G is key to not postponing deployment
- Leverage the global ecosystem of vendors to address the Test Ranges use cases

Thank you



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Achilles Kogiantis, Kiran Rege, Anthony Triolo

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14. ABSTRACT

Current implementations of Cellular Test Range Telemetry are based on the LTE technology, which includes enhancement concepts that have been introduced up to including the Release-14 of the specification standard. Currently, the same specifications standards organization that implemented LTE (3GPP) has just completed the very first release (Rel-15) of the 5G standard. The new 5G standard is intended to be a radically new radio access network and core network design, while maintaining some level of interoperability with the 4G LTE technology. The paper provides an overview of the key new features and concepts that were specified for 5G, and which can offer new capabilities to the Cellular Test Range Telemetry. Specifically, the concepts presented are: expanded channel bandwidths and new operating bands, frame structure and architecture that allows for lower latency and for integration of beamforming to the low-layer signaling operations, new concepts of enhanced handover with zero interruption, additional concepts being worked for use in unlicensed bands and for integrating access and backhaul use of radio nodes. Finally, the paper outlines how can a network evolve to allow co-existence of installed LTE equipment with new 5G equipment that may be introduced, and the migration path from a fully LTE into an exclusively 5G network.

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Cellular, telemetry, long-term evolution(LTE), 5G

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